Flexibility and grid services from hydrogen electrolysers

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ESIG Workshop, Hydrogen Tutorial

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In a low-carbon, low-inertia, low-system strength grid…

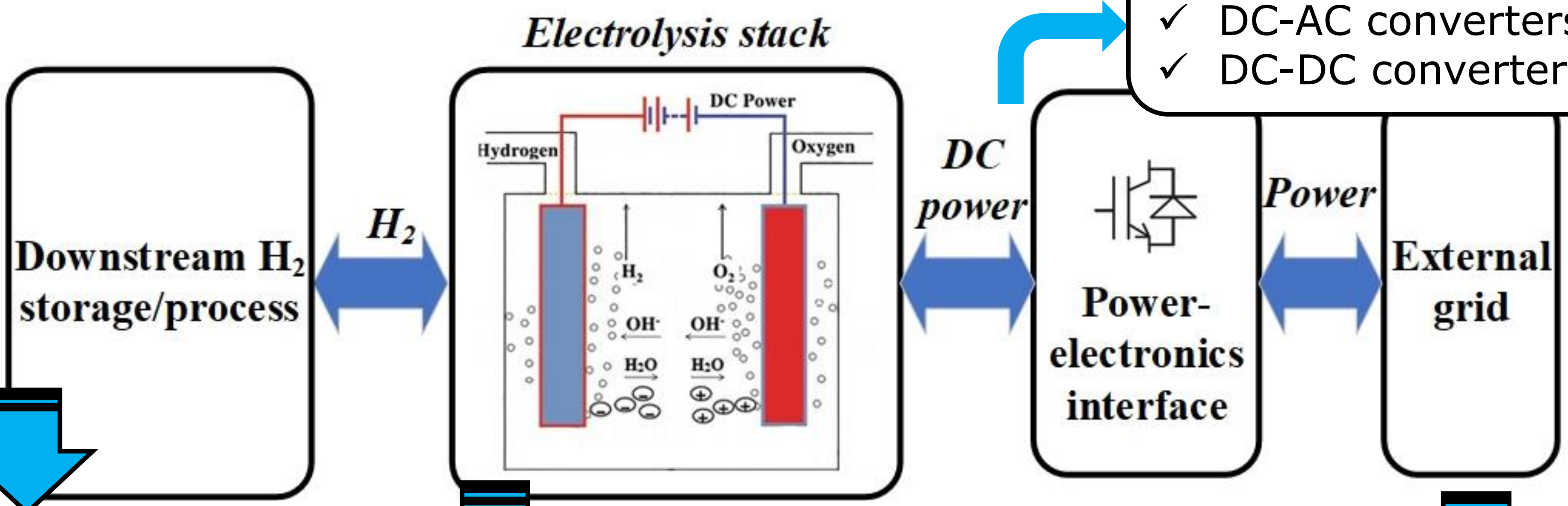
- How do we model and assess electrolysers' capabilities to provide system balancing and dynamic services?
  - Focus here on active power balancing and frequency control ancillary services (FCAS)

- What types of dynamic supports can we get from electrolysers?

- What are the benefits and challenges?

An Overall View on Grid Integration of Hydrogen Electrolyzers

- ✓ Back-to-back converters
- ✓ DC-AC converters
- ✓ DC-DC converters



Wide range of applications!

- ✓ Proton Exchange Membrane (PEM)
- ✓ Alkaline
- ✓ Solid Oxide

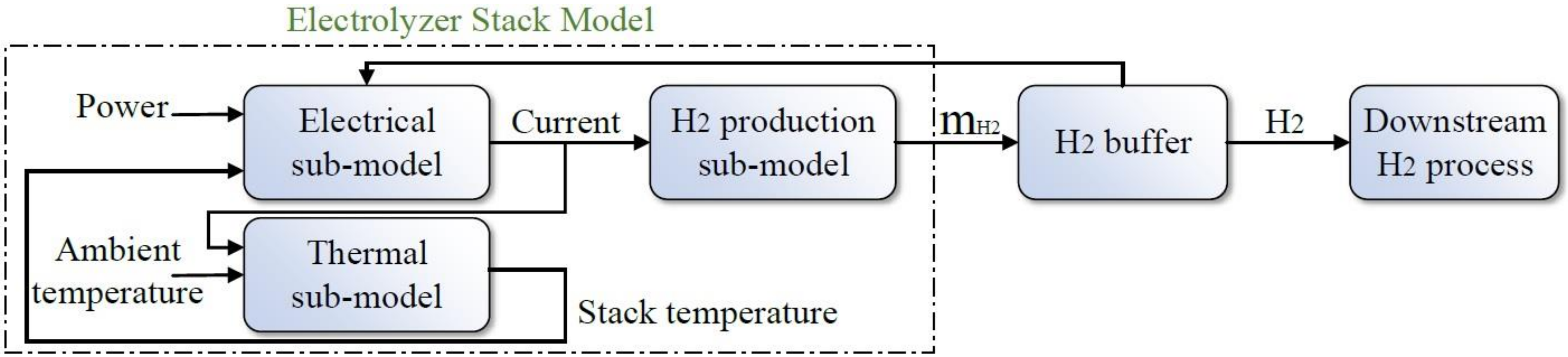
- ✓ Large-scale
- ✓ Small-scale

- ✓ AC bulk power system (transmission, renewable-rich, low-inertia)
- ✓ DC/AC micro-grids and distribution grids
- ✓ DC-link in renewable hubs (PV, wind)

Unified Dynamic Modelling Framework

- **Three** modelling components:
  - Electrolysis stack
  - Power-electronics interface and control
  - Downstream hydrogen process/buffer

- **Electrolysis stack**:
  - Electrical circuit representation
  - Hydrogen production sub-model
  - Thermal sub-model and its impact on converter control part



M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

Power electronics interface and controls

- **Grid interface and controls**
  - Grid Following control
  - Virtual Synchronous Machine (VSM) control

- **FCAS type** (power reference setting strategy)
  - Contingency FCAS
    - Fast Frequency Response and Primary Frequency Response
      - droop control
      - sustained droop control
      - RoCoF-based control
  - Regulation FCAS
  - Virtual Inertia (from VSM control)

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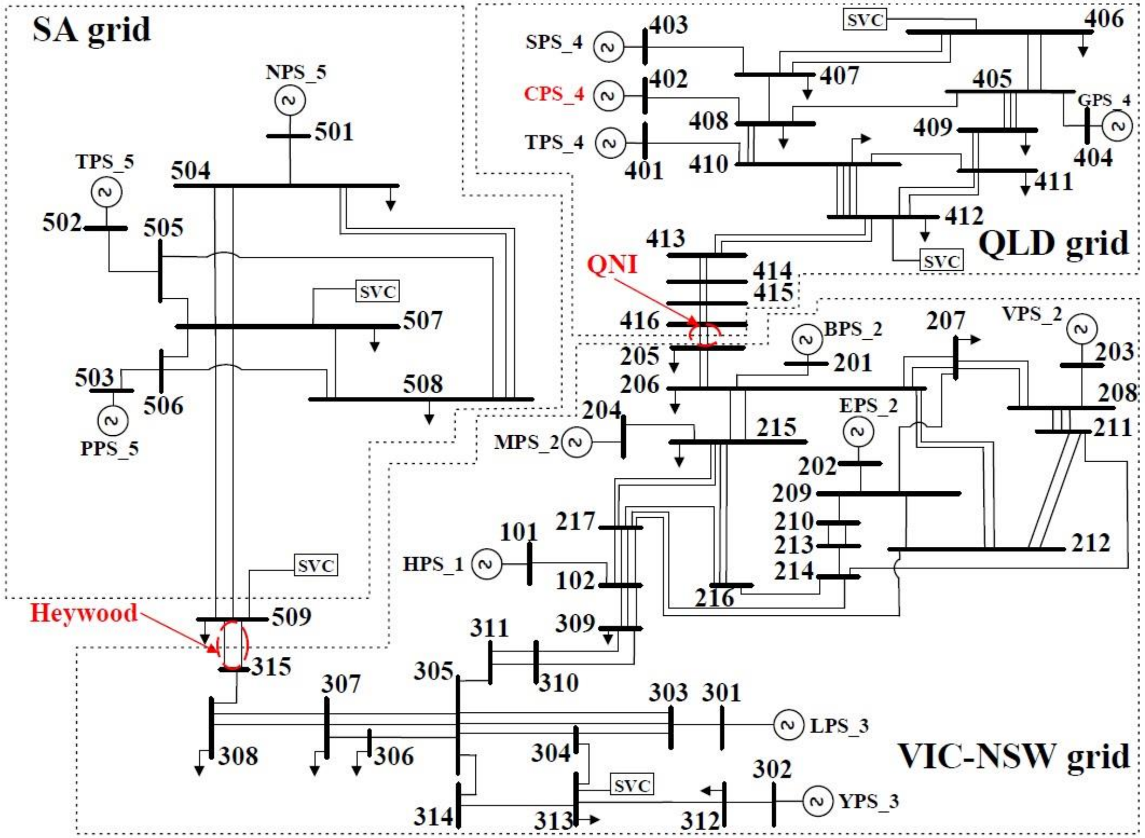
Case Studies (1/3): Fast Frequency Response from Electrolysers

Electrolyser benefits in low-inertia systems

- Electrolyser's frequency support capability in the context of Australian 50% renewable energy target by 2030
- **Contingency**: the largest generating unit outage in Queensland with total capacity of 667 MW at t=40s

Generation and load data

Case Study	*States*	*Synchronous Generation [GW]*	*Non-synchronous Generation [GW]*		*Load [GW]*
			PV	*Wind*	
Case-1	QLD	3.34	1.44	1.77	5.5
	VIC-NSW	11.4	5.58	5.36	17.6
	SA	1.12	0.48	1.07	2.3



Modified 14-generator NEM grid with 50% renewable penetration

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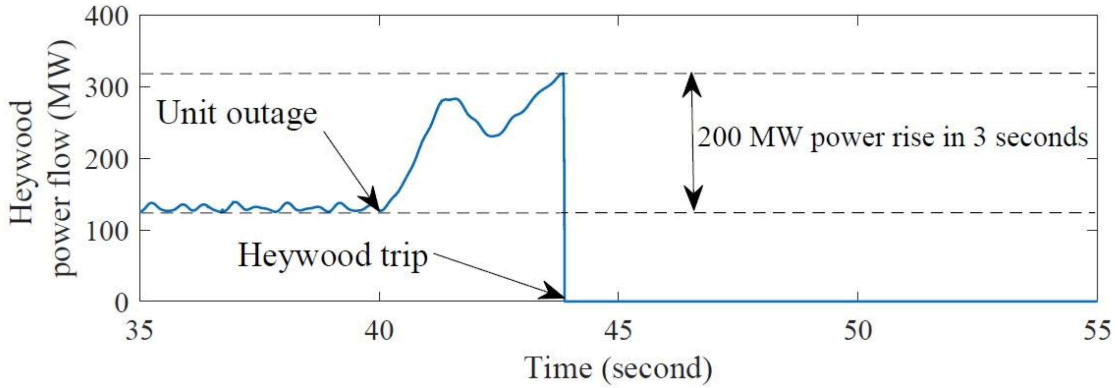
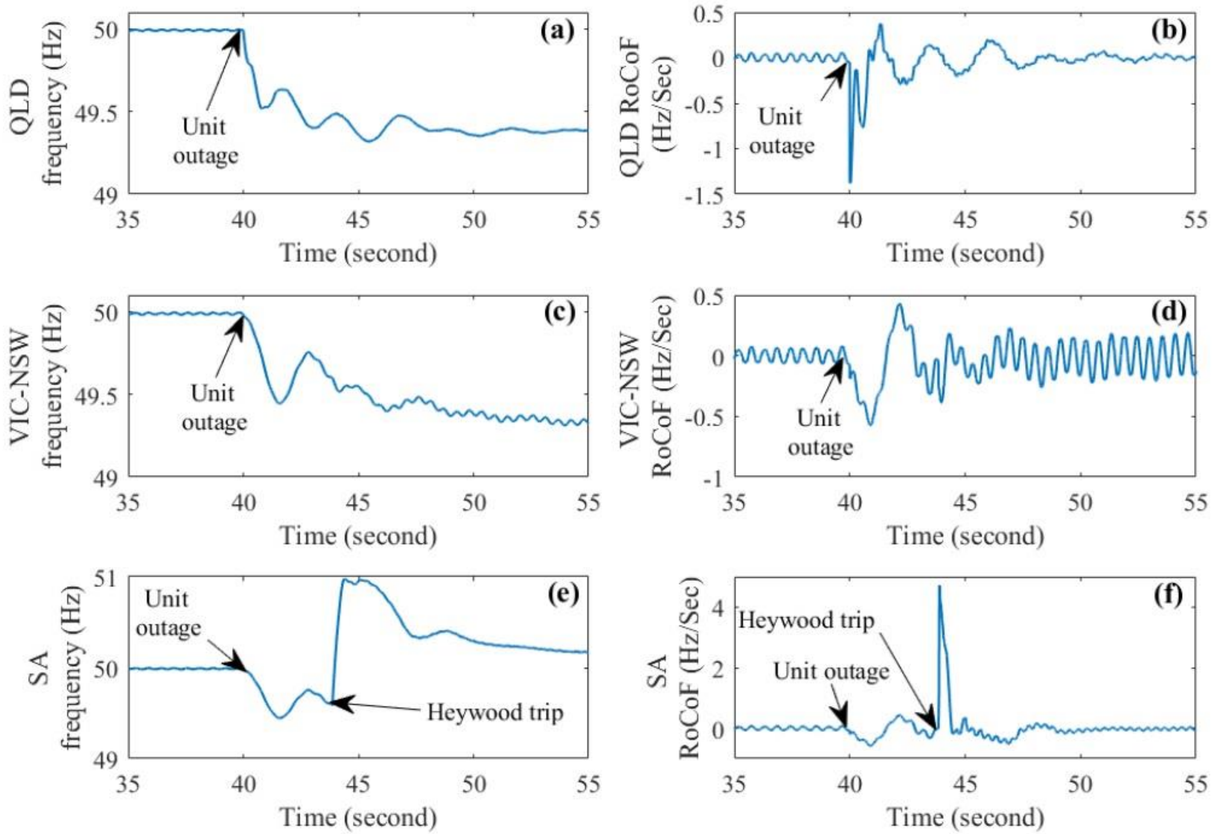
Case Studies (1/3): Fast Frequency Response from Electrolysers

Base case results (no electrolyser)

- **Different frequency dynamics** in States
- Significant **frequency drop** in all states (below 49.4 Hz)
- A **high RoCoF** value in Queensland



Heywood active power flow

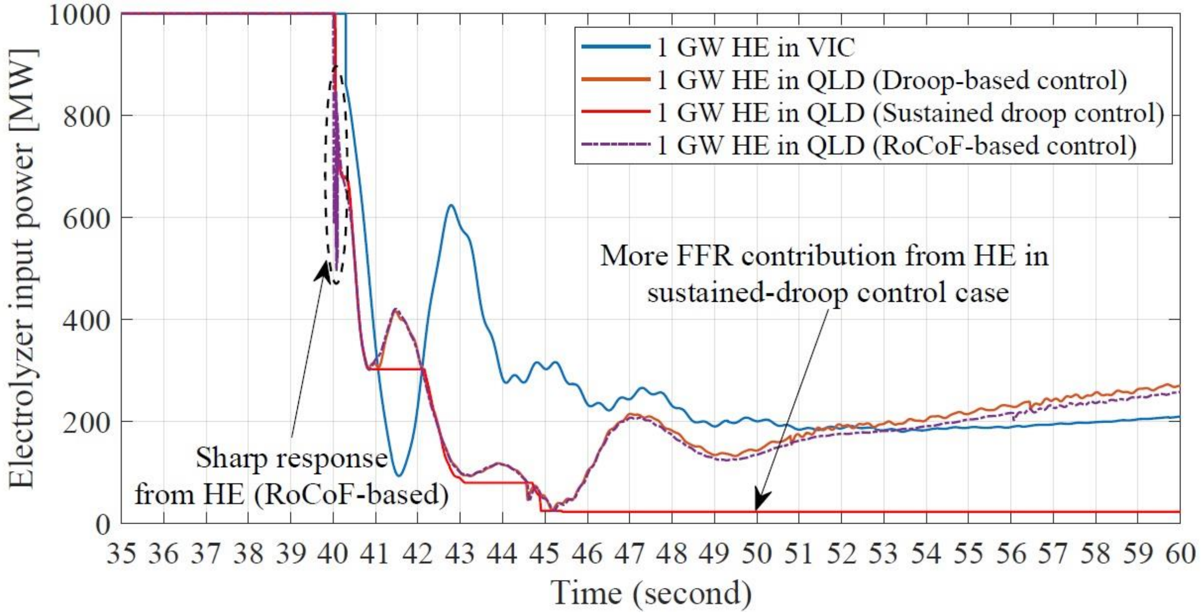


Frequency and RoCoF in States

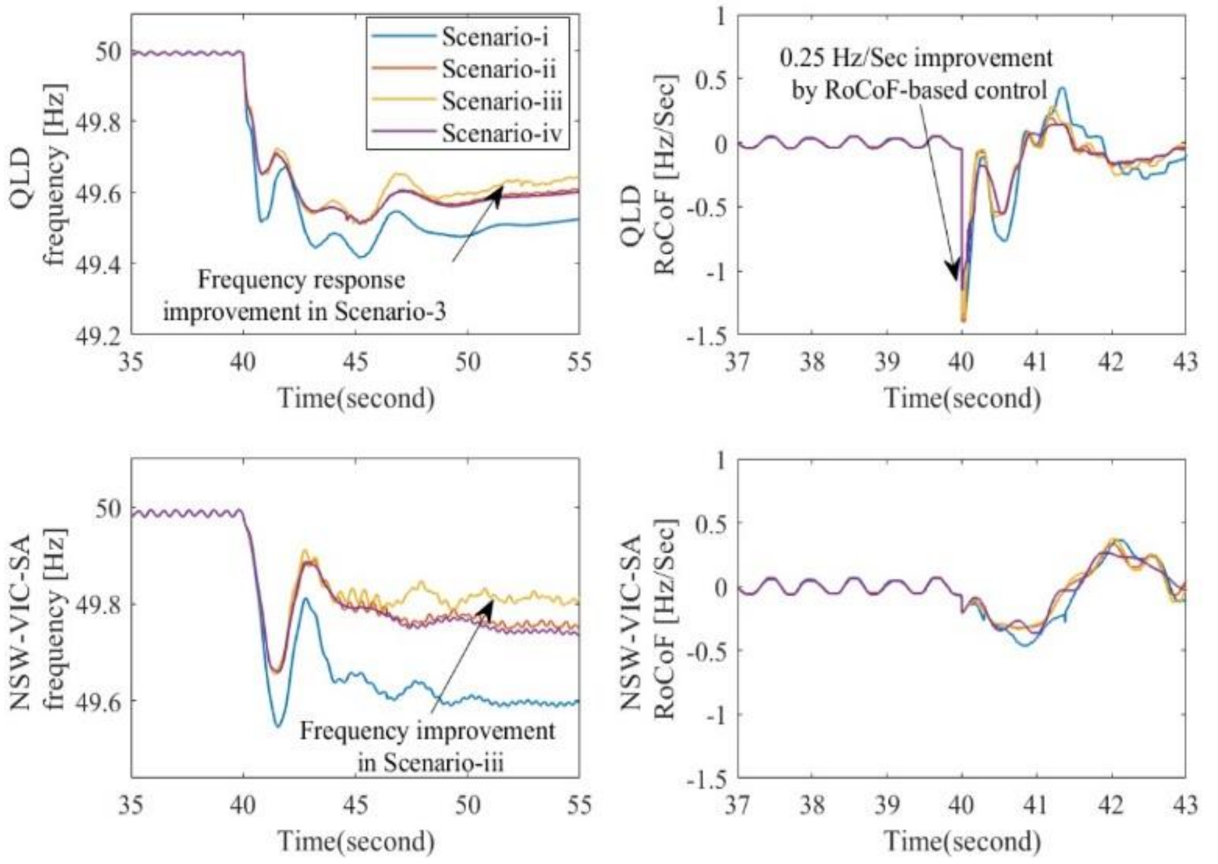
M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

Case Studies (1/3): Fast Frequency Response from Electrolysers

- The following PEM electrolyser scenarios are studied:
  - i) 1GW HE in VIC grid, droop control
  - ii) 1 GW HE in QLD grid, droop control
  - iii) 1 GW HE in QLD grid, sustained droop control
  - iv) 1 GW HE in QLD grid, RoCoF-based control



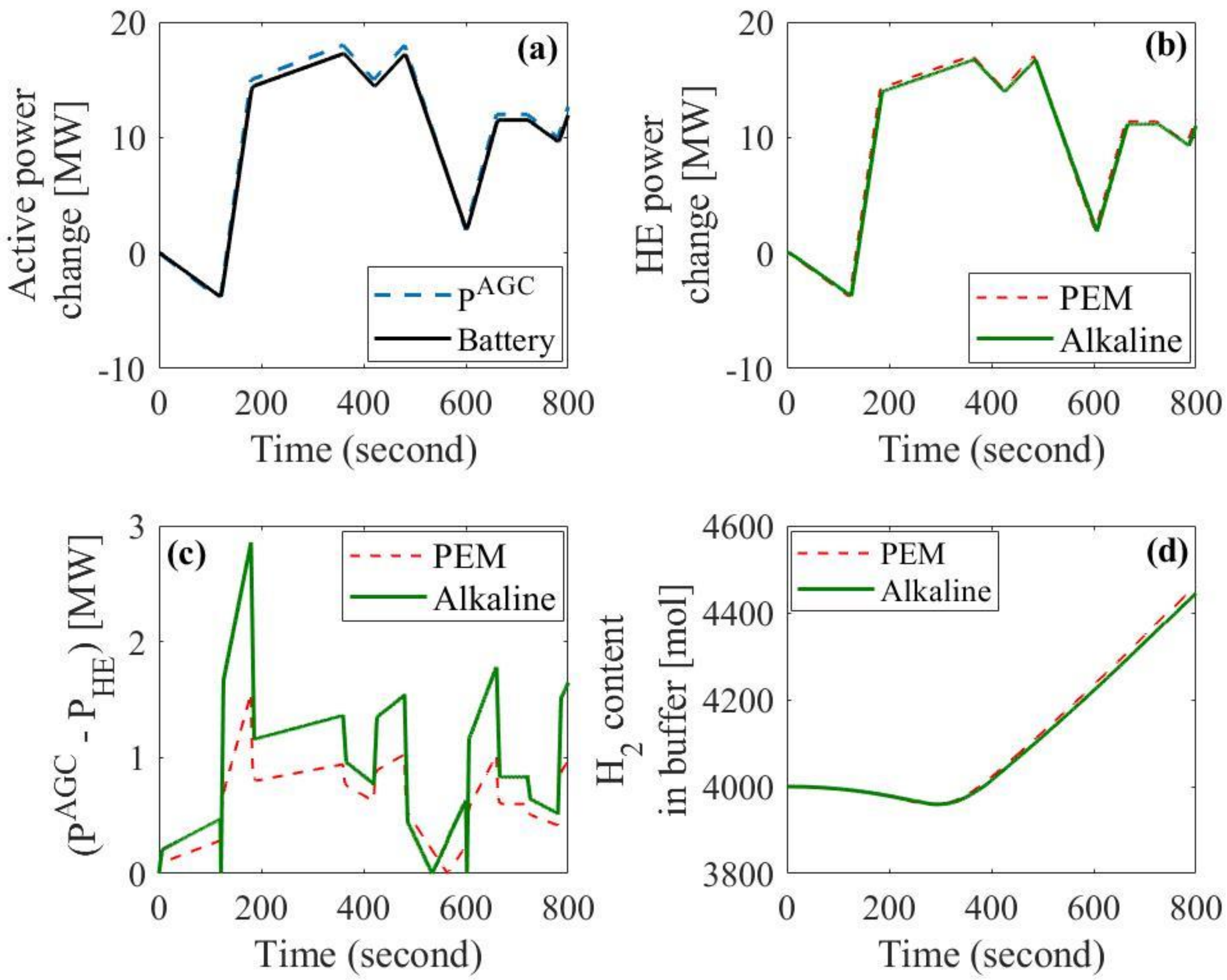
Primary frequency response from electrolysers



System dynamics in different scenarios

M. Ghazavi Dozein, A. Jalali and P. Mancarella, "Fast Frequency Response From Utility-Scale Hydrogen Electrolyzers," in *IEEE Transactions on Sustainable Energy*, 2021.

Case Studies (2/3): Regulation FCAS from Electrolysers



M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

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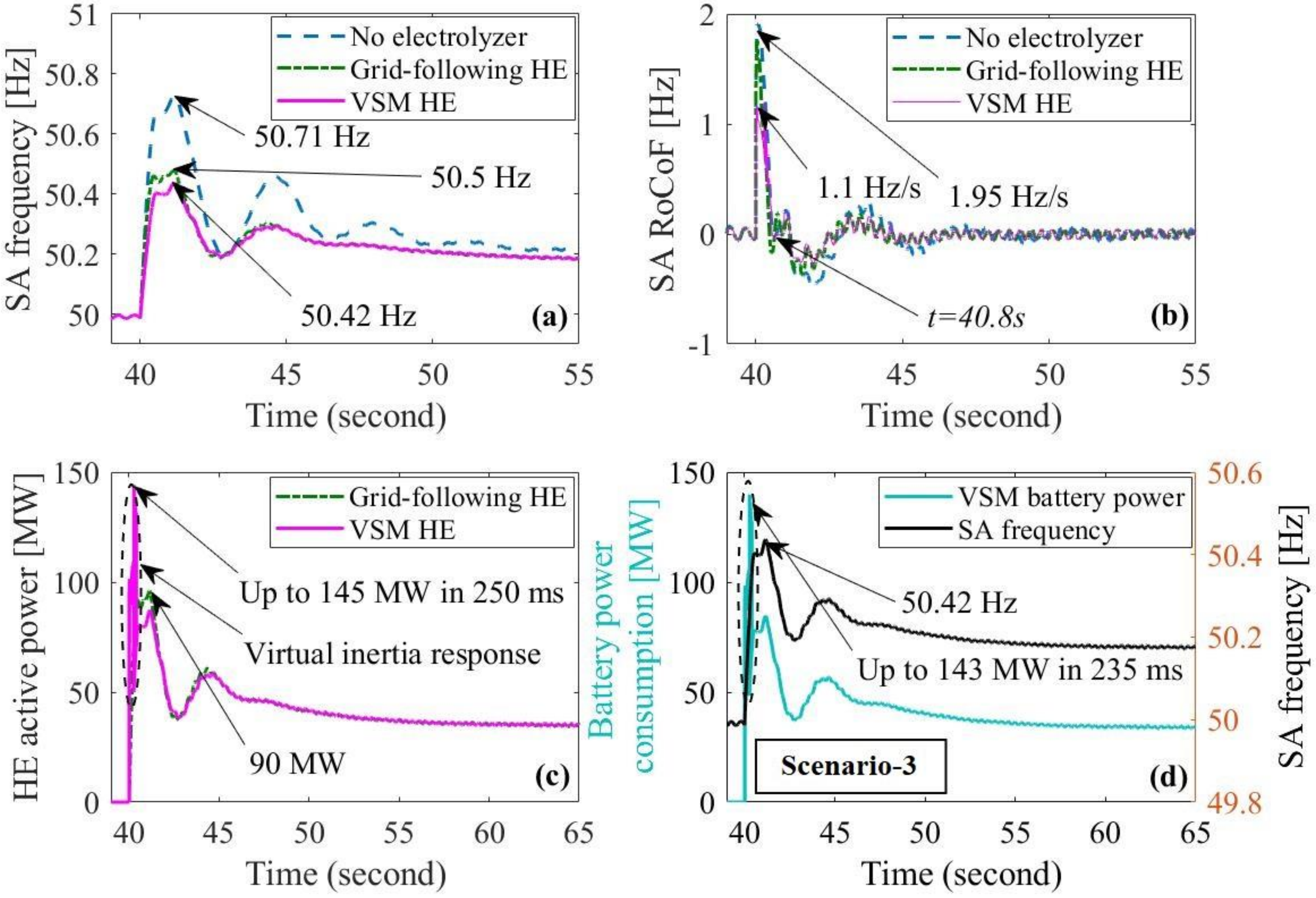
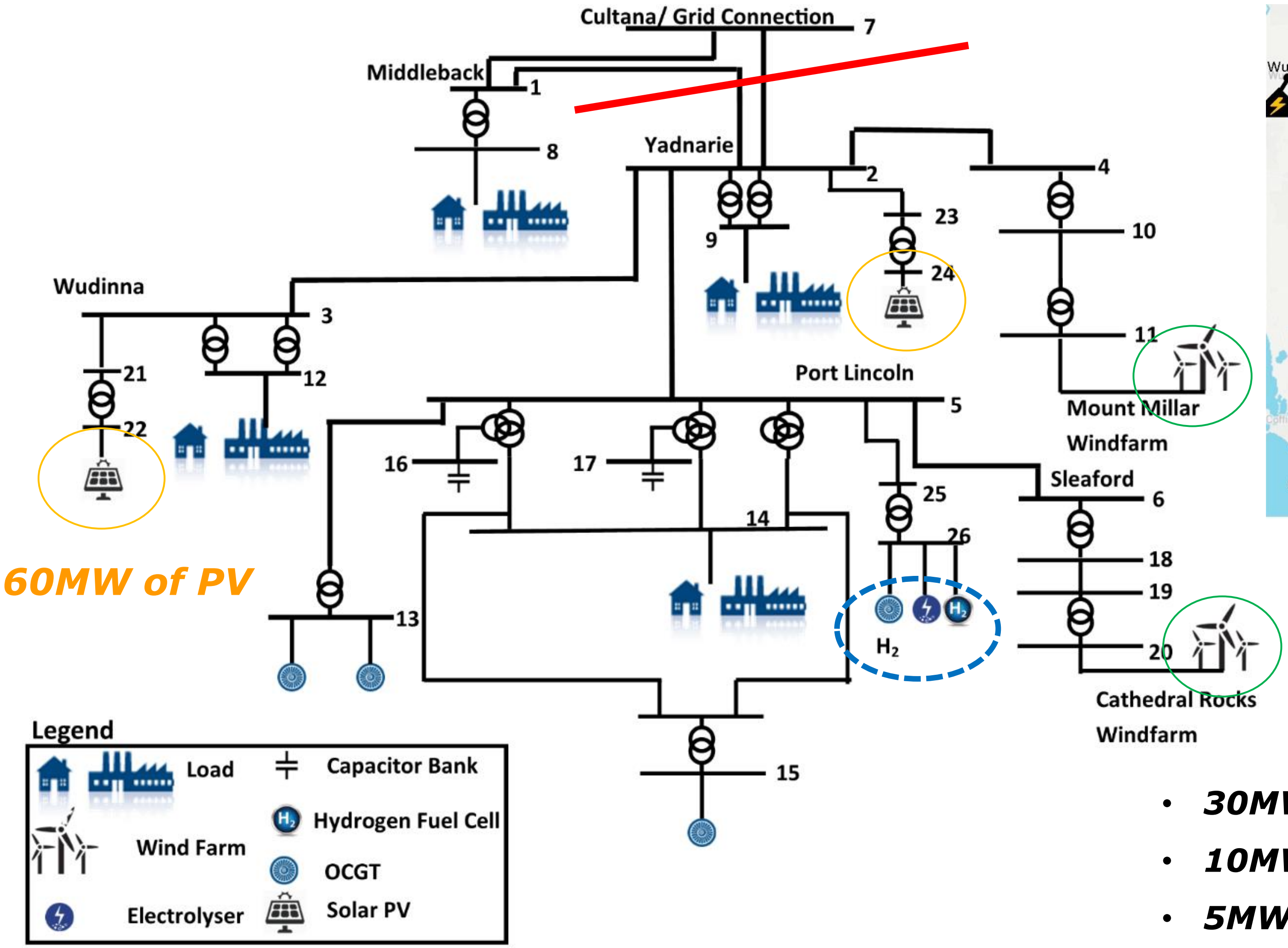
Case Studies (3/3): Virtual Inertia Response from Electrolysers

- **Contingency**: Heywood interconnector trips at *t*=40s
- Before the trip, 110 MW was being transferred from SA to VIC
- 150 MW PEM electrolyser in SA
  - ✓ Grid-following
  - ✓ VSM control
- Scenario-3: 150 MW VSM battery

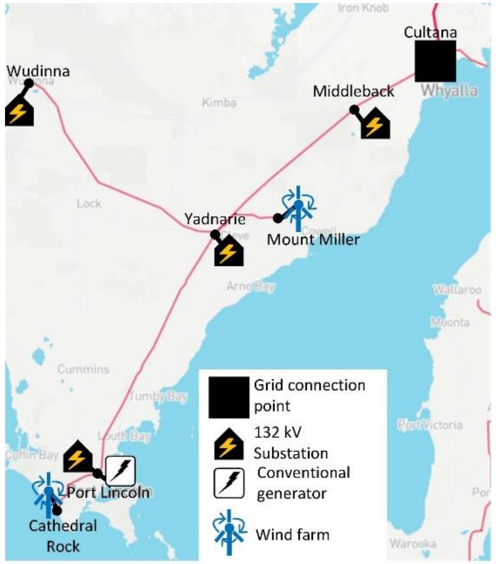


M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

Ongoing applications: Hydrogen-RES energy hubs



60MW of PV

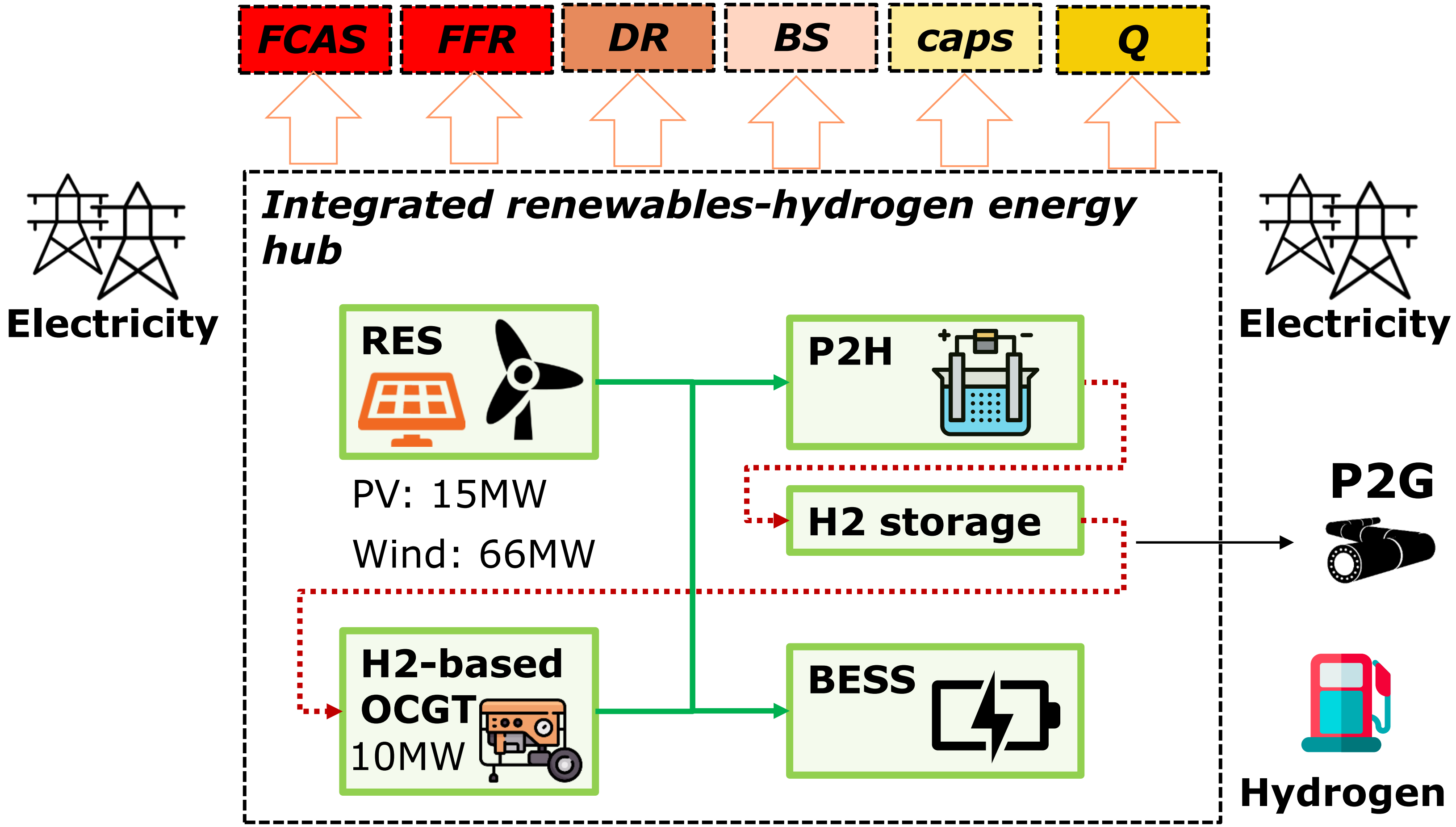


136MW of Wind

- *30MW Electrolyser*
- *10MW H2 OCGT*
- *5MW Fuel Cell*
- *100MWh of H2 Storage*
- *73MW OCGT*

J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power Syst. Research*, 2020

RES-hydrogen grid and market services



J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power Syst. Research*, 2020

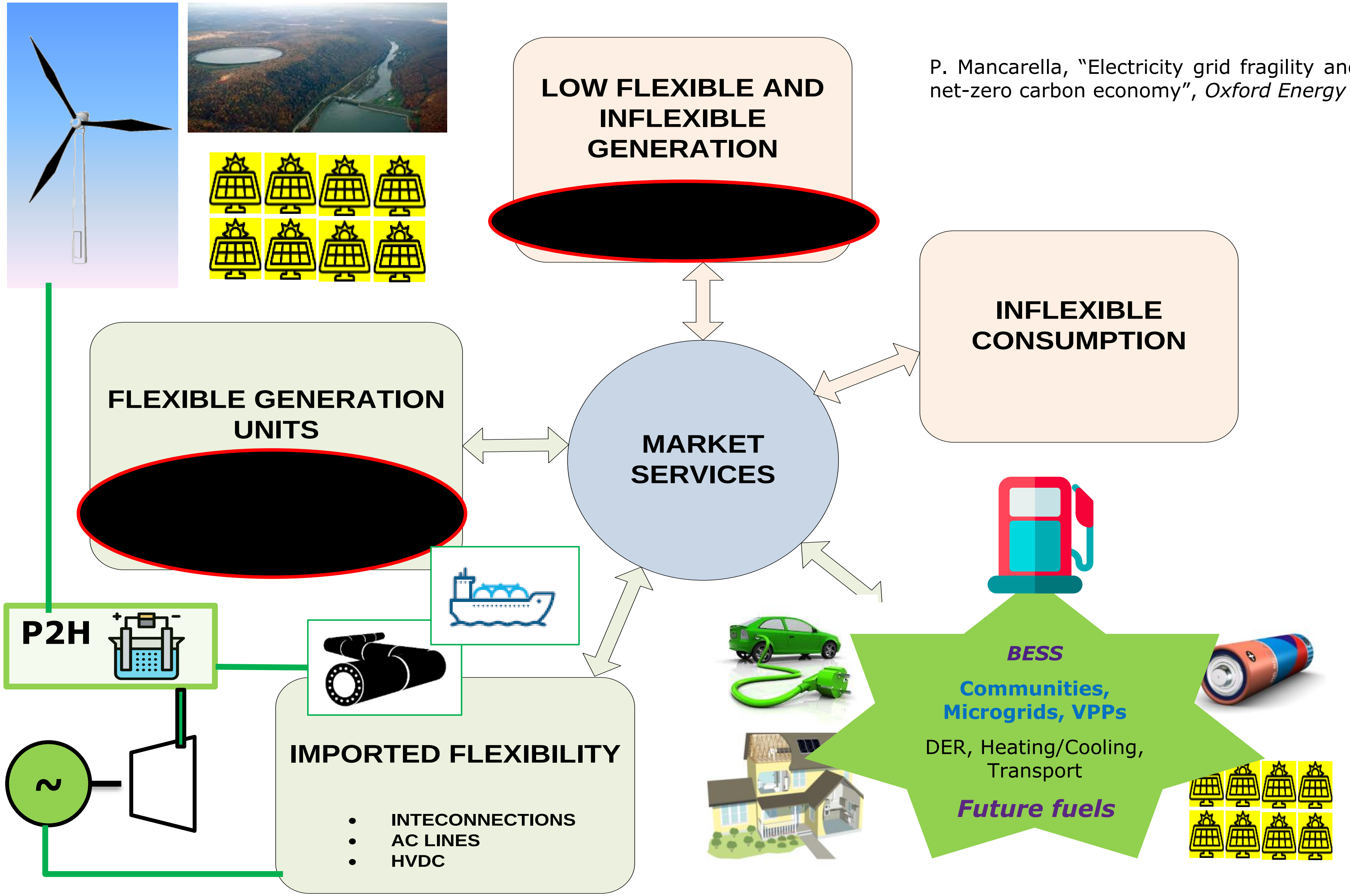
S. Riaz and P. Mancarella, "Modelling and characterization of flexibility from DER", *IEEE Transactions on Power Systems*, 2021

Key Remarks

- The modelling and studies presented here are based on **a unified dynamic modelling framework** for utility-scale electrolysis plants we recently proposed
- **PEM electrolysers** have great **potential** in providing
  - **Fast frequency response (and** primary frequency response**)**
  - **Regulation** FCAS
  - **Virtual inertia response** (if equipped with **virtual synchronous machine** control)
- **Alkaline electrolysers** have great **potential** in providing **regulation** FCAS
- Frequency control from electrolysers **may reduce the need for frequency control-oriented battery installation**
- **Market opportunities** are becoming mature
- Possible **challenges** in providing frequency control from electrolysers
  - Limited converter capacity
  - Interactions with operational constraints in hydrogen production → **cross-sector planning** is required

Sustainability, reliability and resilience in future grids

P. Mancarella, “Electricity grid fragility and resilience in a future net-zero carbon economy”, *Oxford Energy Forum*, 2020



Acknowledgments

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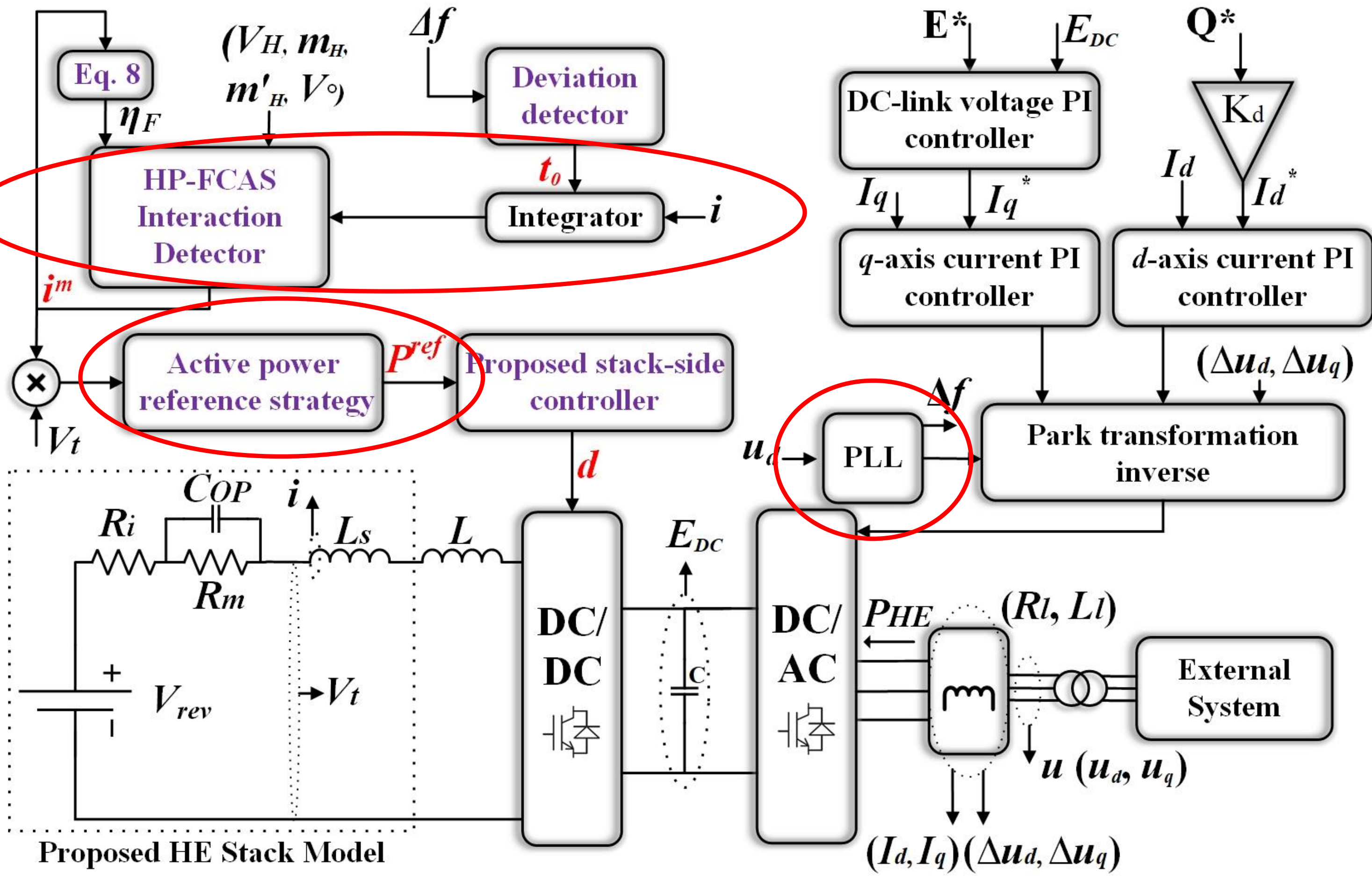
HE Dynamic Model including Power-Electronics Interface and Control

- ***Grid-following*** **control**
  - **Synchronization via phase-locked loop (PLL)**
- **Reactive power** control via grid-side (DC/AC) converter
- **Active power** control via stack-side (DC/DC) converter
- Consideration of **H_2 operational constraints** in converter control loops
- **Active power reference** strategy for frequency stability response provision



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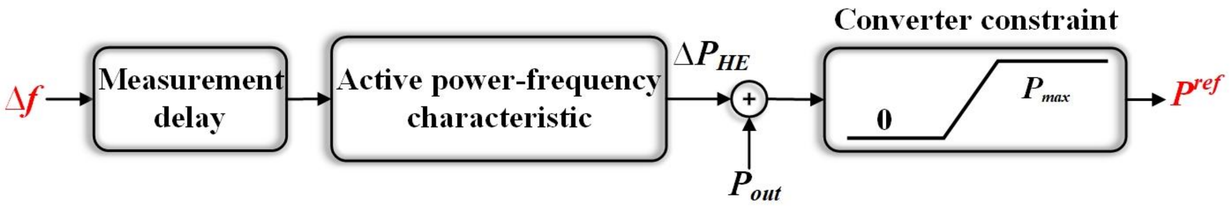
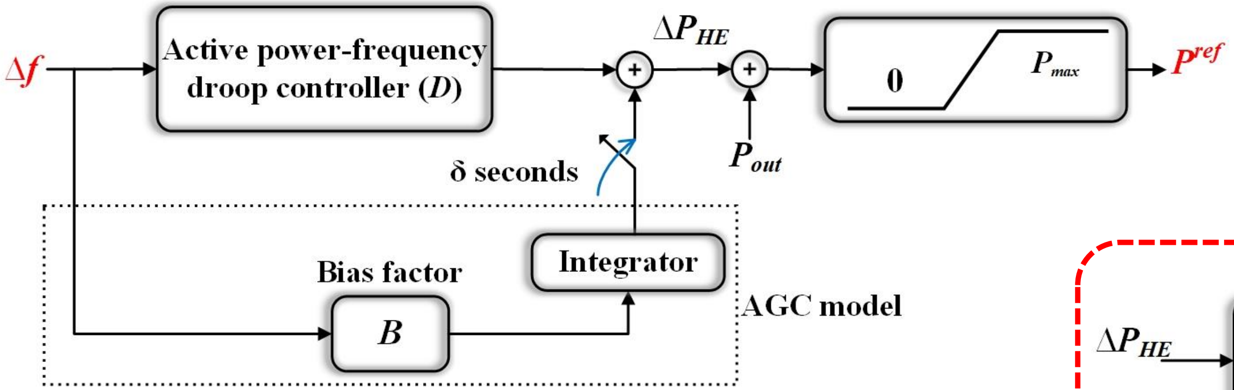
Active Power Reference Strategy (1/2)



(a)

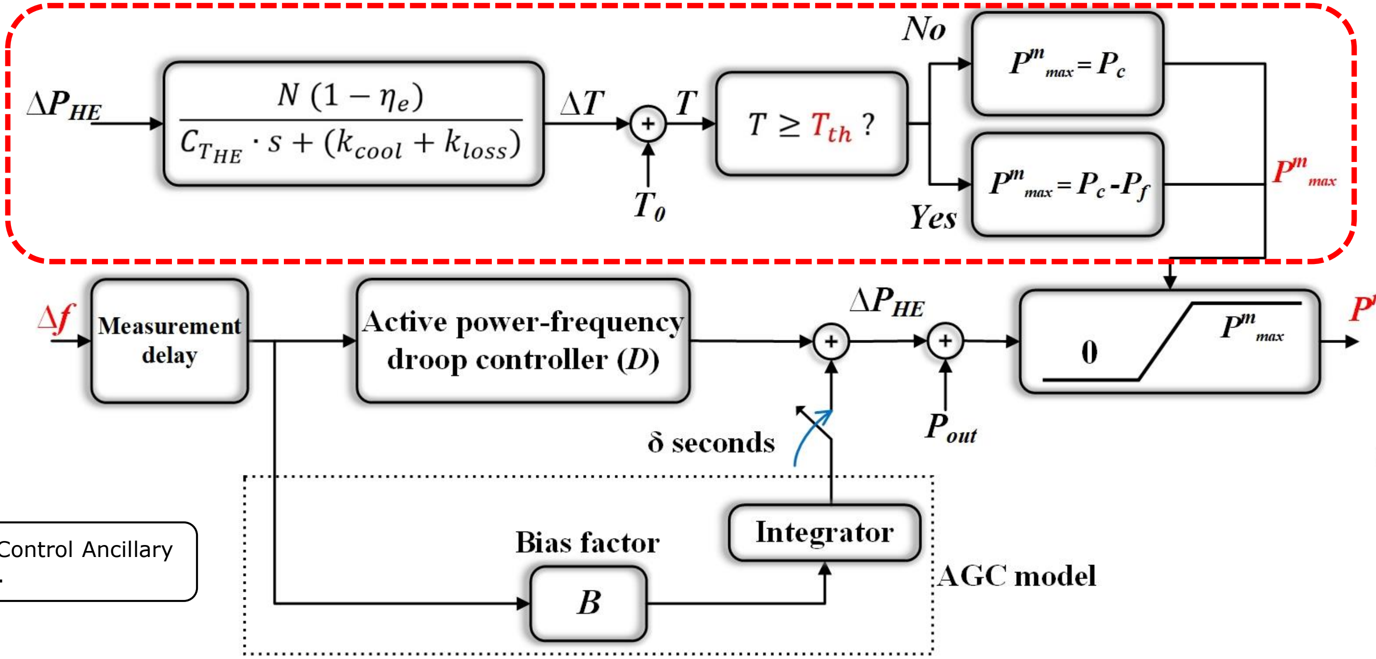


(b)

(a) **Contingency** FCAS

(b) **Contingency** and **Regulation** FCAS

(c) FCAS for **long time durations** (**thermal** sub-model impacts)



(c)

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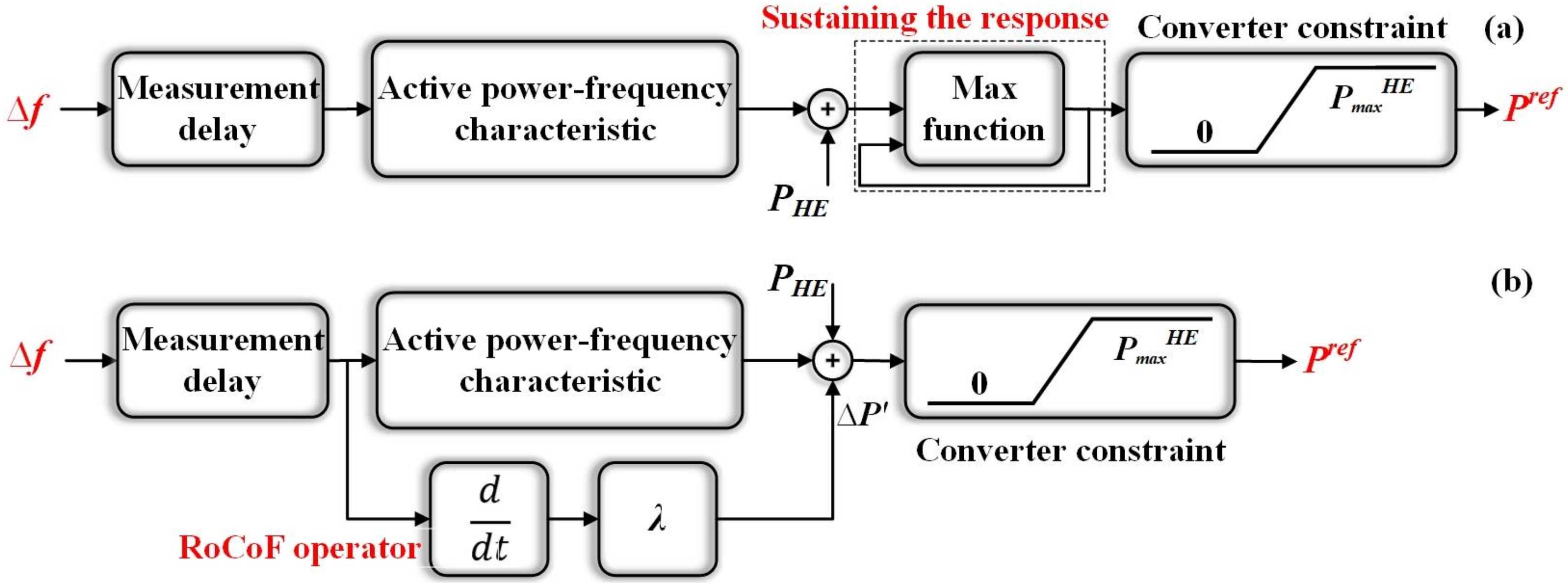
FCAS= Frequency Control Ancillary Services

Active Power Reference Strategy (2/2)

- **Sustained droop response** via the strategy presented in (a)
- **RoCoF-based response** via the strategy presented in (b)
- Both strategies can further be developed to account for **thermal** sub-model impacts



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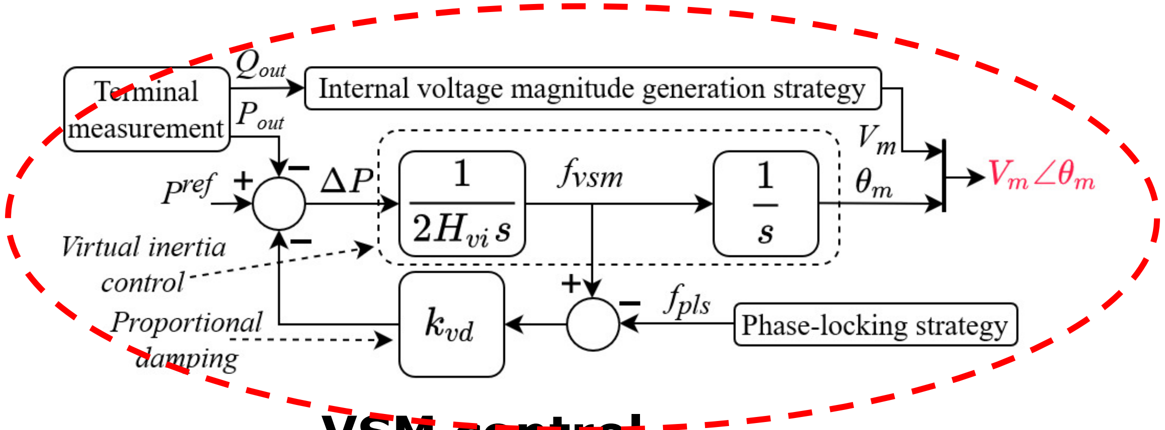
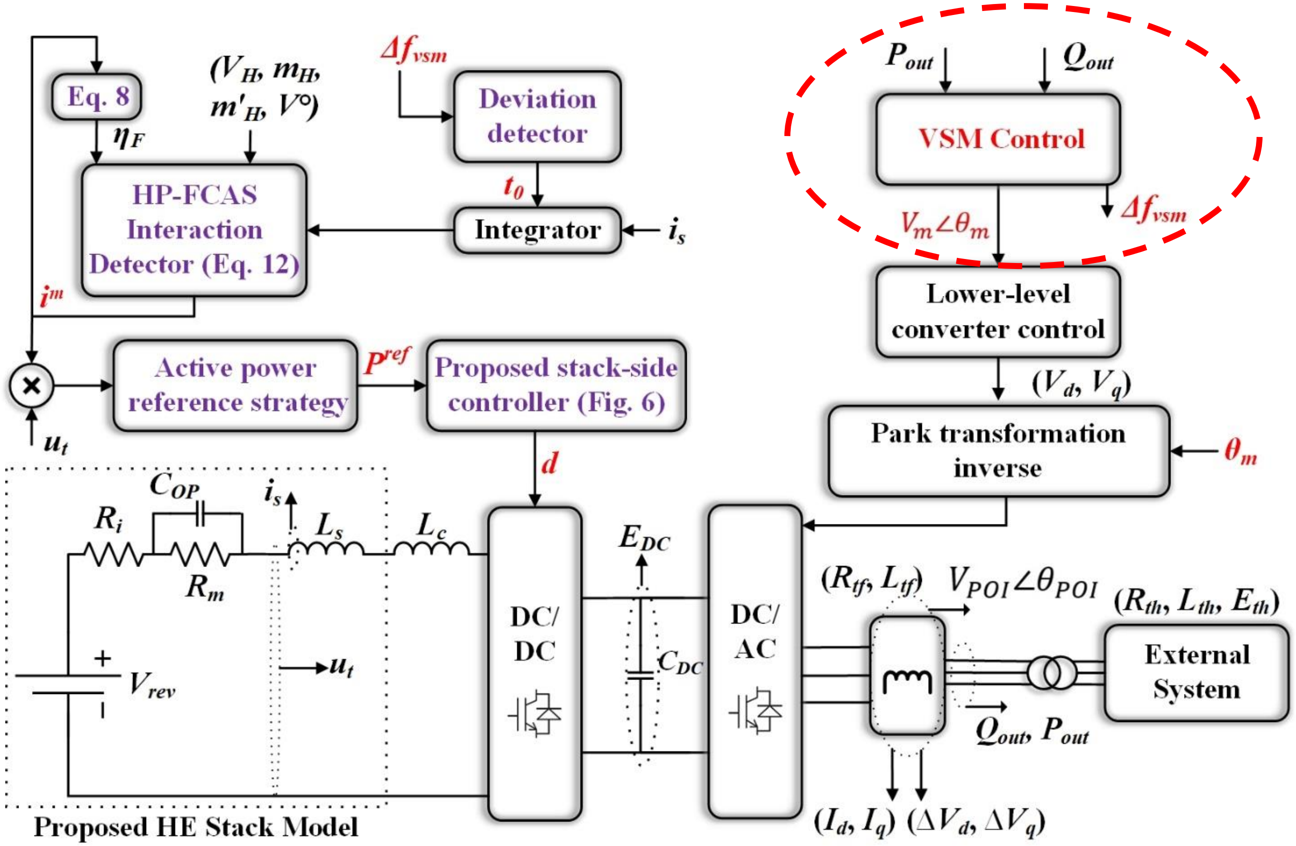
HE Dynamic Model including Power-Electronics Interface and Control

- ***Virtual synchronous machine (VSM) control***
  - **Internally** supplied by a **voltage phasor** for synchronization purposes
- **Virtual inertia response** provision in addition to FCAS



VSM control



M. Ghazavi Dozein, A. M. De Corato, and P. Mancarella, "Virtual Inertia Response and Frequency Control Ancillary Services from Hydrogen Electrolyzers," *Under Review, IEEE Transactions on Power Systems,* 2021.

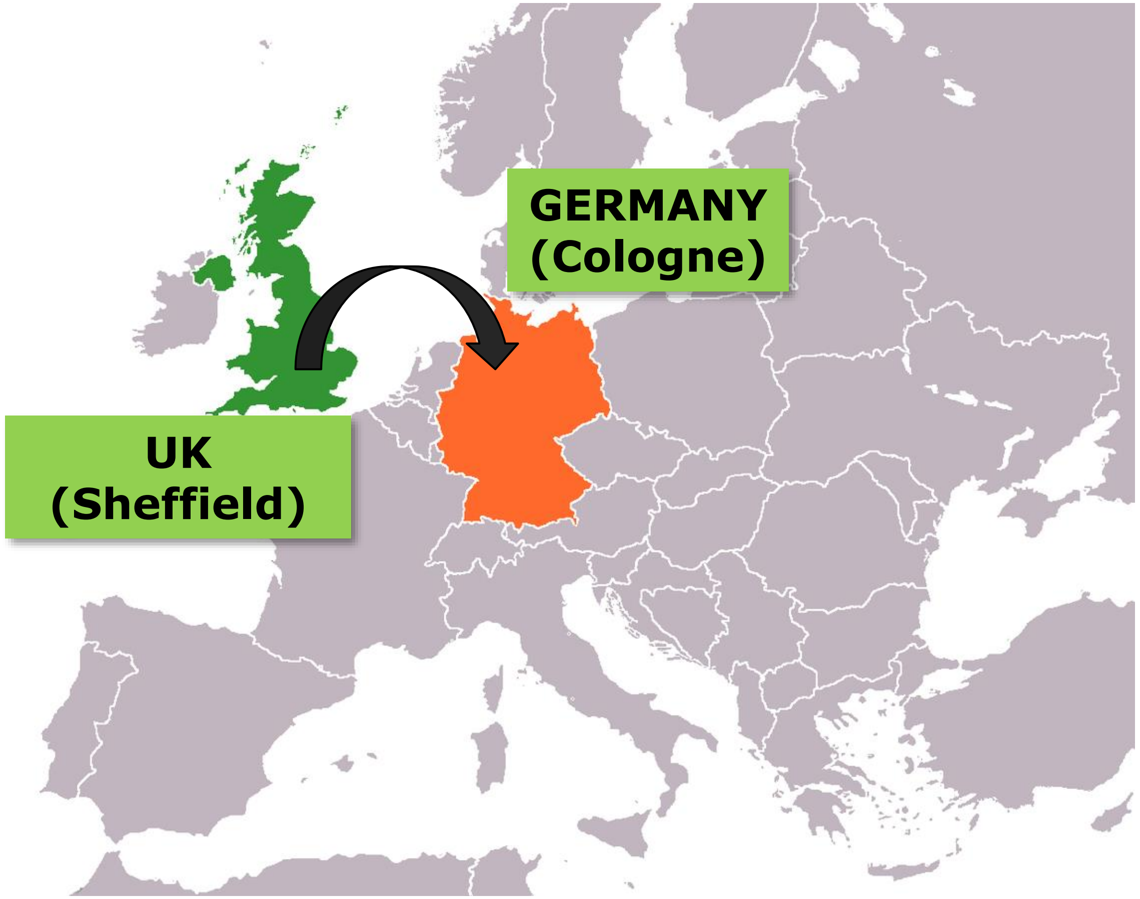
Electrolyser dynamic model equipped with VSM control

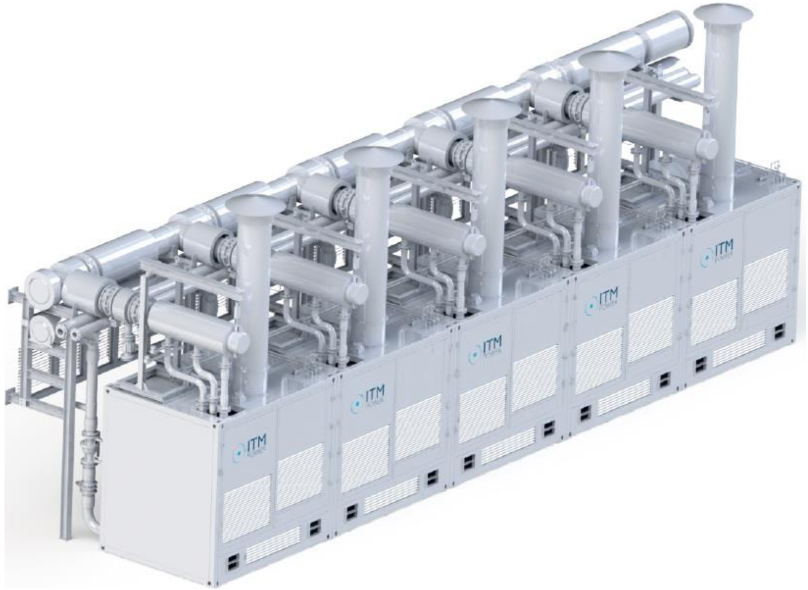
FCAS= Frequency Control Ancillary Services

Real-Life Examples (1/3)

ITM POWER
Energy Storage | Clean Fuel

REFHYNE





World's largest PEM electrolyser

Capacity: 100 MW (initially 10 MW), plan for 1000+ MW

Structure: Modular electrolyser

Voltage level: 11 kV (each module)

Grid application: Grid balancing, frequency stability, and voltage stability and control

Response time: in the order of milliseconds

Further information: www.itm-power.com/refhyne

Real-Life Examples (2/3)

Number of electrolysers: 3

Type: PEM (Siemens)

Rating: 1.3 MW, peak power up to 2 MW each

Voltage level: 22 kV

Ramp up/down time: in the order of second(s)

Grid application: Grid balancing and system frequency supports

Further information: www.energiepark-mainz.de

Real-Life Examples (3/3)

Project: HyStock

Country: the Netherlands

Technology: 1 MW PEM electrolyser + 1 MW PV

Grid application: ancillary service provision

Further information: www.energystock.com

Project: H2Future

Country: Austria

Technology: 6 MW PEM electrolyser

Grid application: frequency stability supports

Further information: www.h2future-project.eu

Project: Ontario IESO

Country: Canada

Technology: MW scale PEM and alkaline electrolysers (e.g., 2.5 MW)

Grid application: frequency regulation

Further information: www.cummins.com

Project: HyBalance

Country: Denmark

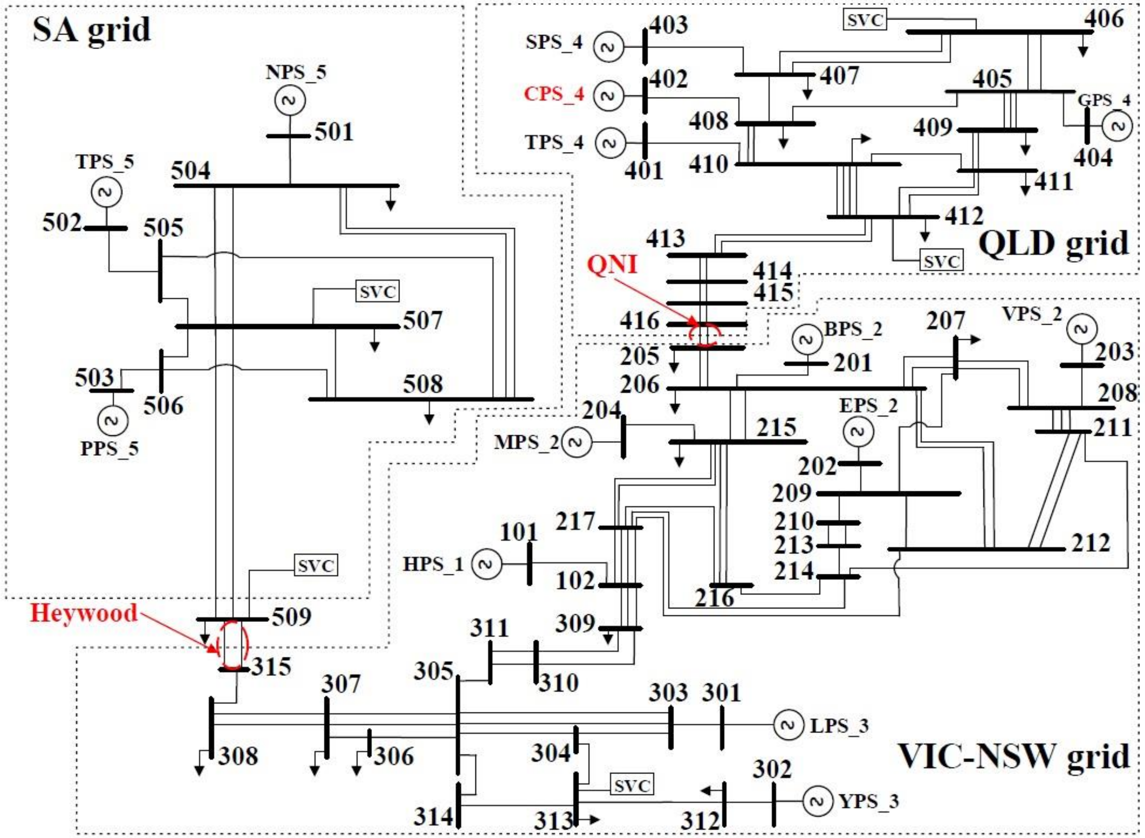
Technology: 1.2 MW PEM electrolyser

Grid application: grid balancing

Further information: www.hybalance.eu

Case Studies: FFR Interaction with Operational/Converter Constraints

- **Contingency**: the Heywood trip at *t*=40s. Before the trip, 110 MW was being transferred from SA to VIC
- The following cases are studied:
  - ✓Case-1: System with **no electrolyzer**
  - ✓Case-2: 1 GW electrolyzer in SA, **no converter overloading capability**
  - ✓Case-3: 1 GW electrolyzer in SA with **10% converter's overloading capability**
  - ✓Case-4: 1 GW electrolyzer in SA grid, and **modelling of hydrogen buffer and downstream H_2 process**



Modified 14-generator NEM grid with 50% renewable penetration

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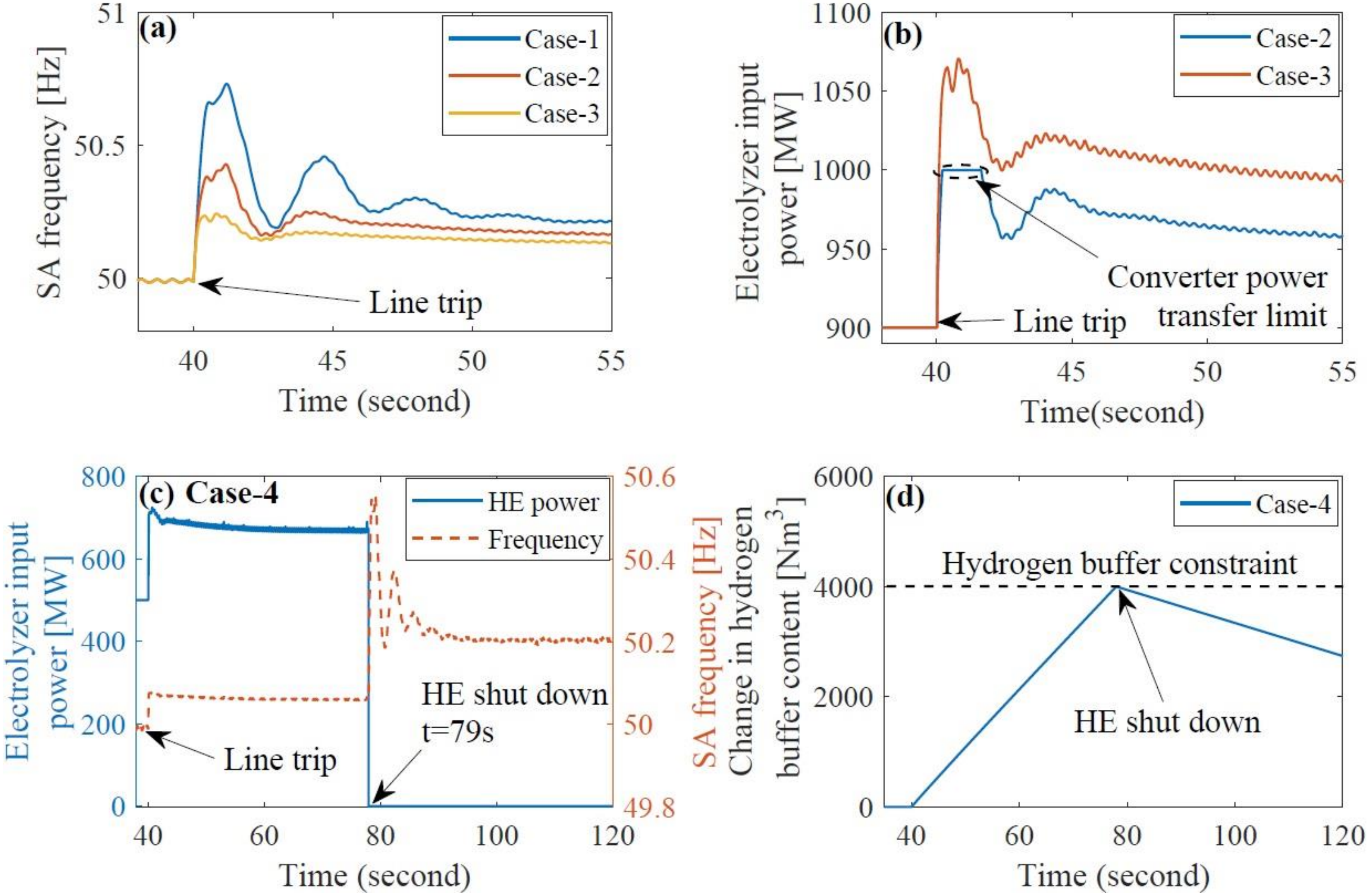

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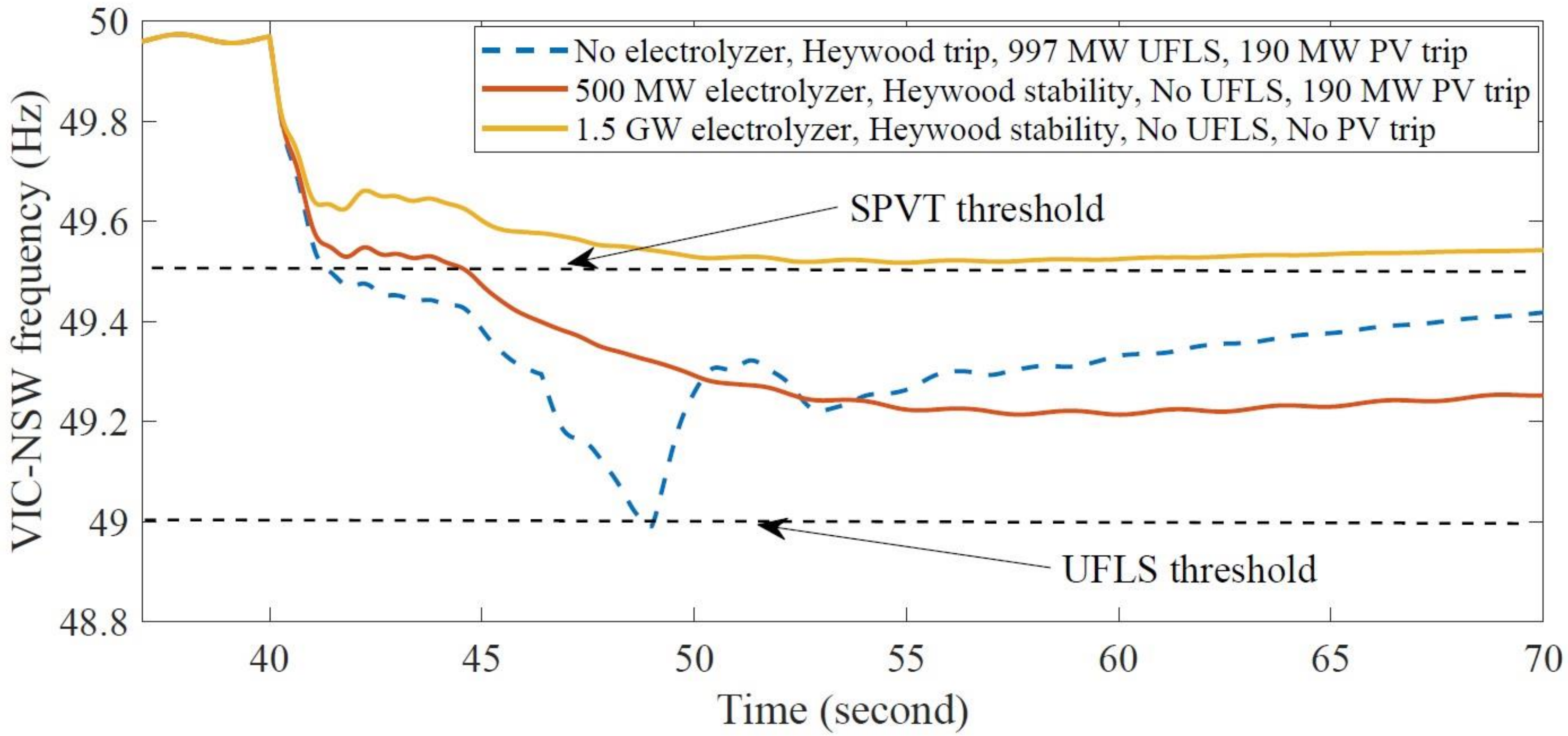
Take-Home Messages

- There are **two potential challenges** in fast frequency response provision from electrolysis plants
  - **Limited converter capacity**
    - Solution: converter overloading
  - **Operational constraints in downstream hydrogen process/buffer**
    - Hydrogen-electricity cross-sector planning for system security supports

Case Studies: Frequency Resilience Support from Electrolysers

- We have investigated the frequency resilience benefits from electrolysers in the context of the August 2018 separation event in Australia



Take-Home Message: Prevention of cascading failures via frequency control from electrolysers

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